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Kimoto et al.

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(54) **PUSH-PULL CIRCUIT, DC/DC CONVERTER, SOLAR CHARGING SYSTEM, AND MOVABLE BODY**

USPC 320/101, 117, 121
See application file for complete search history.

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(58) **Field of Classification Search**
CPC Y02T 10/7216; H02J 1/102; H02J 3/32; H02J 3/383; B60L 22/10; H02M 1/4225; H05B 33/0815

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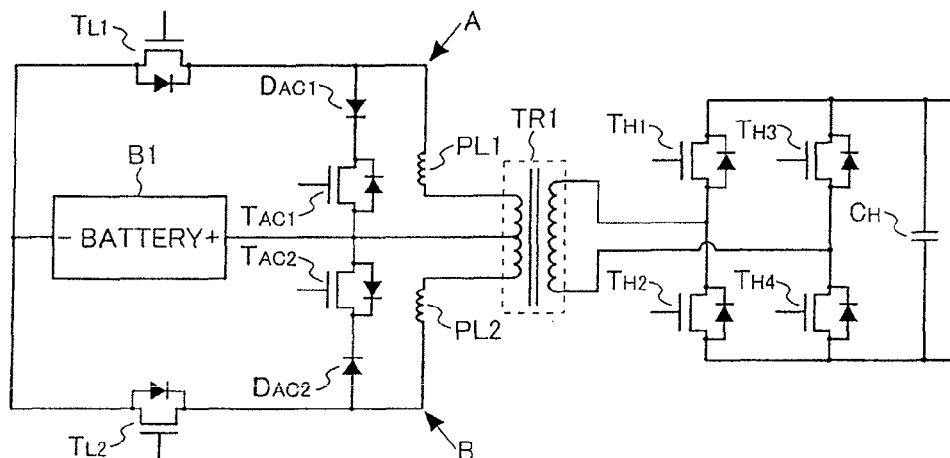
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(57) **ABSTRACT**

A push-pull circuit comprising: a push-pull first switching element and second switching element; a first rectifier element; a third switching element for switching a pathway between conductance and cutoff, the pathway leading from a connection point between the first switching element and an inductive load via the first rectifier element to a connection point between a DC power source and a center tap of the inductive load; a second rectifier element; and a fourth switching element for switching a pathway between conductance and cutoff, the pathway leading from a connection point between the second switching element and the inductive load via the second rectifier element to a connection point between the DC power source and the center tap of the inductive load.

10 Claims, 18 Drawing Sheets



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Fig. 1

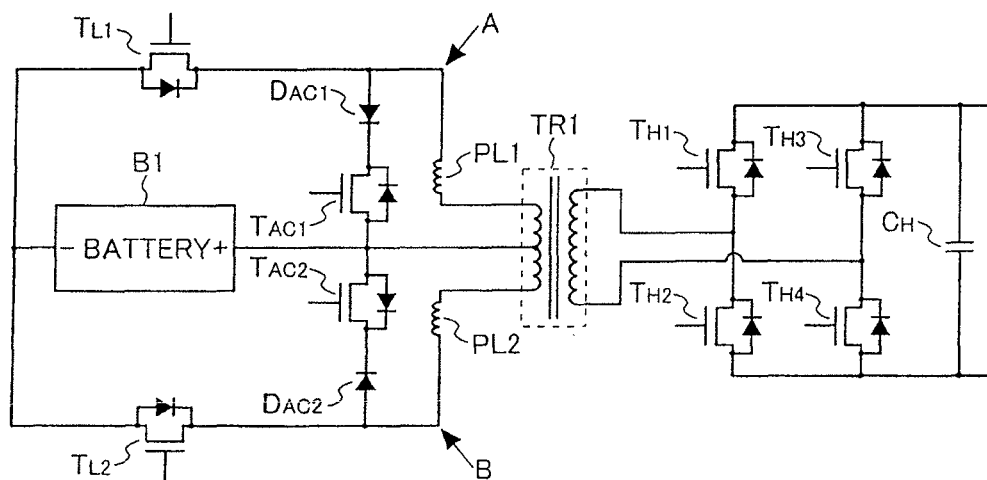


Fig. 2

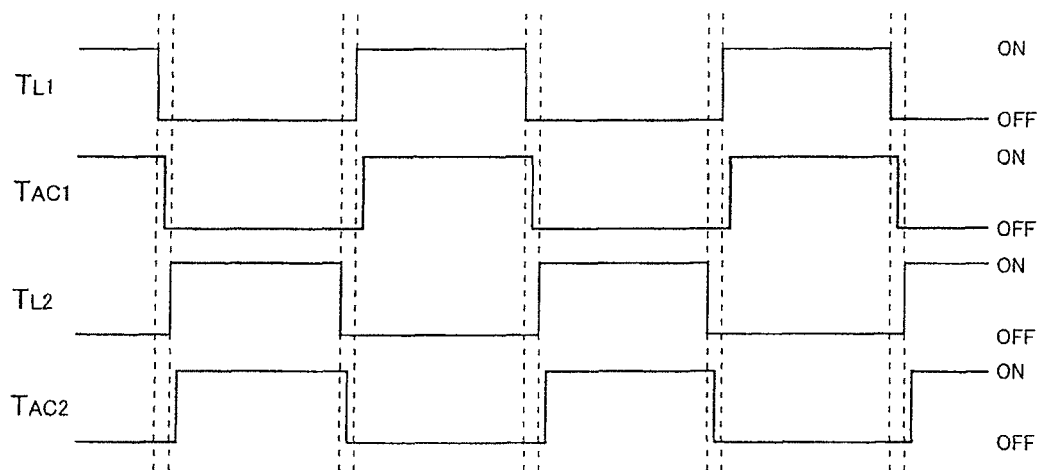
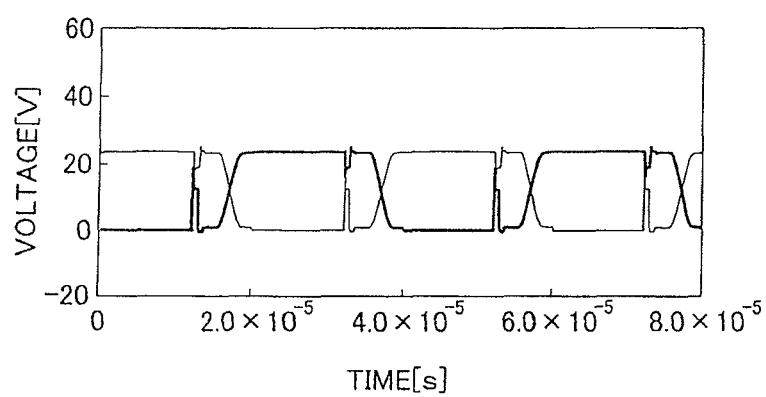


Fig. 3



RELATED ART

Fig. 4

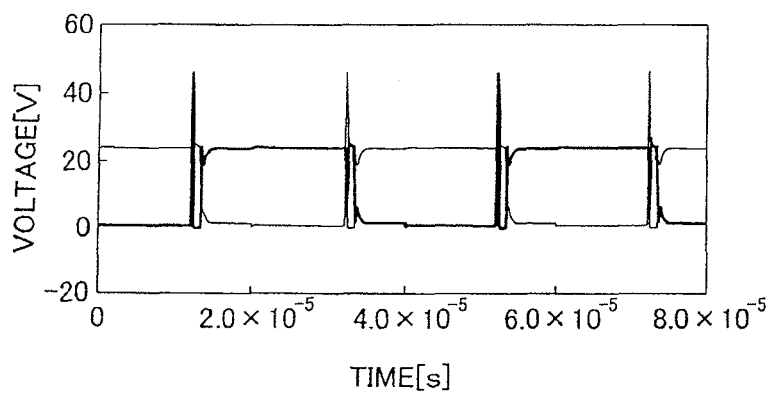


Fig. 5

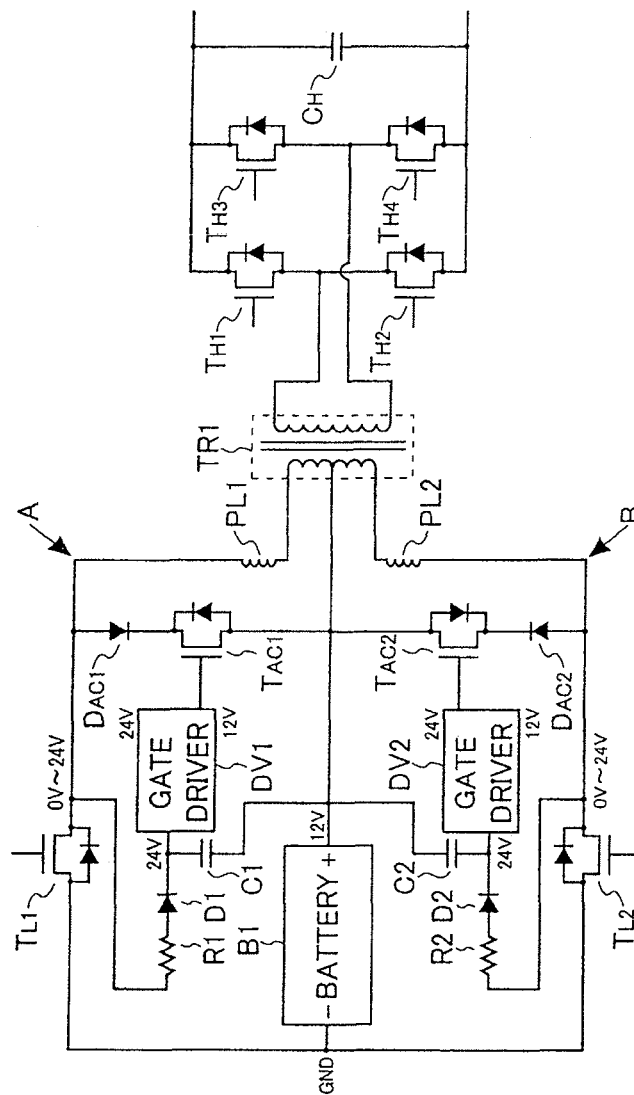


Fig. 6

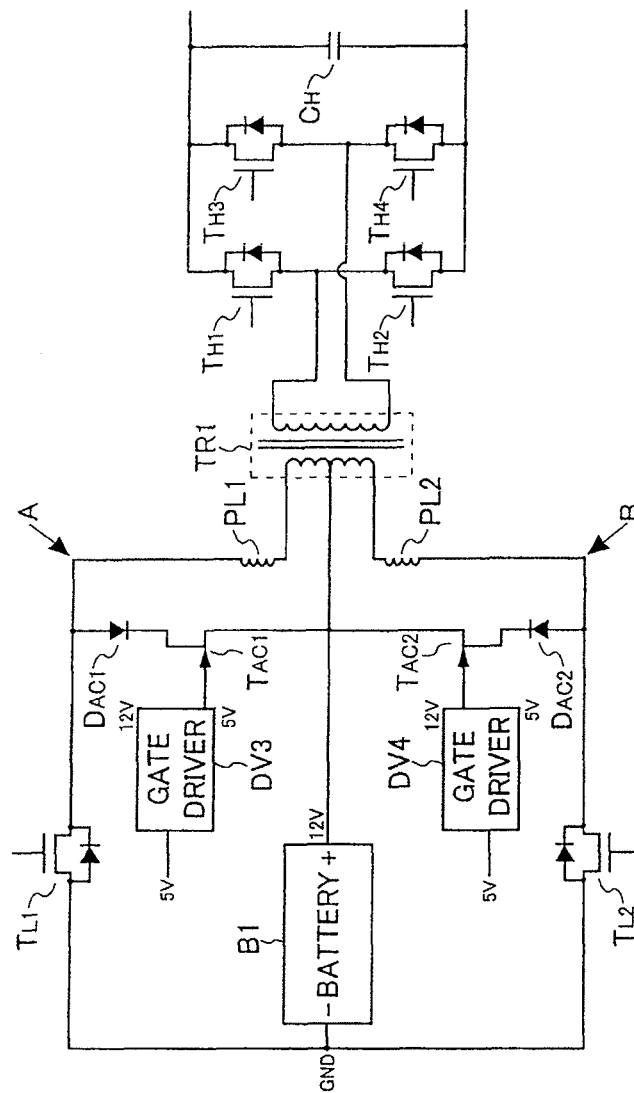


Fig. 7

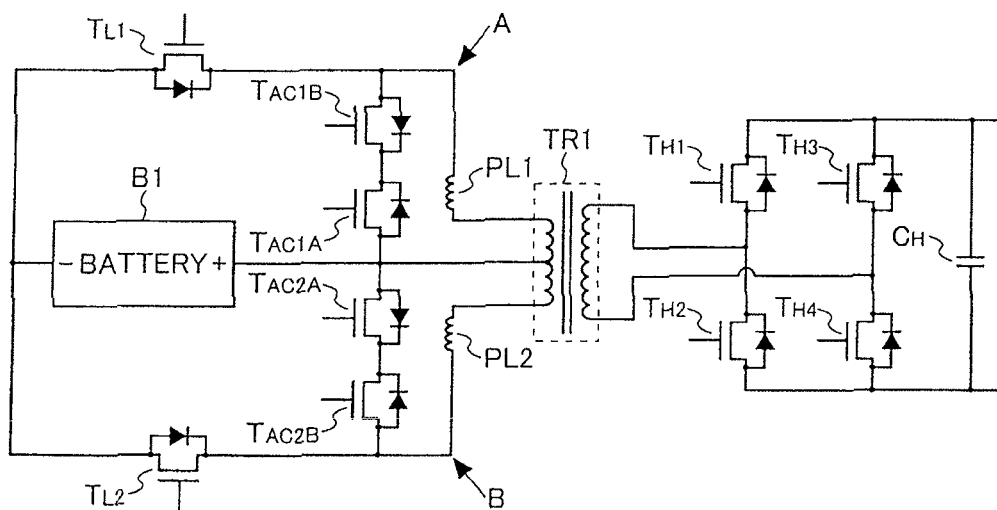


Fig. 9

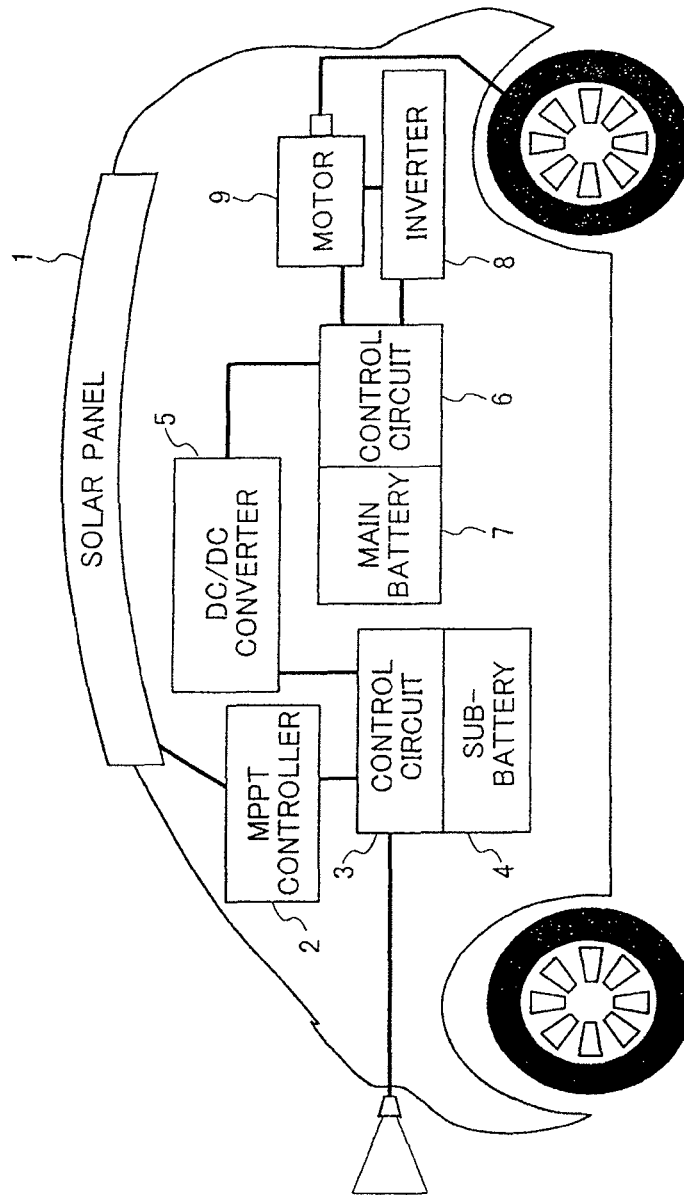


Fig. 10

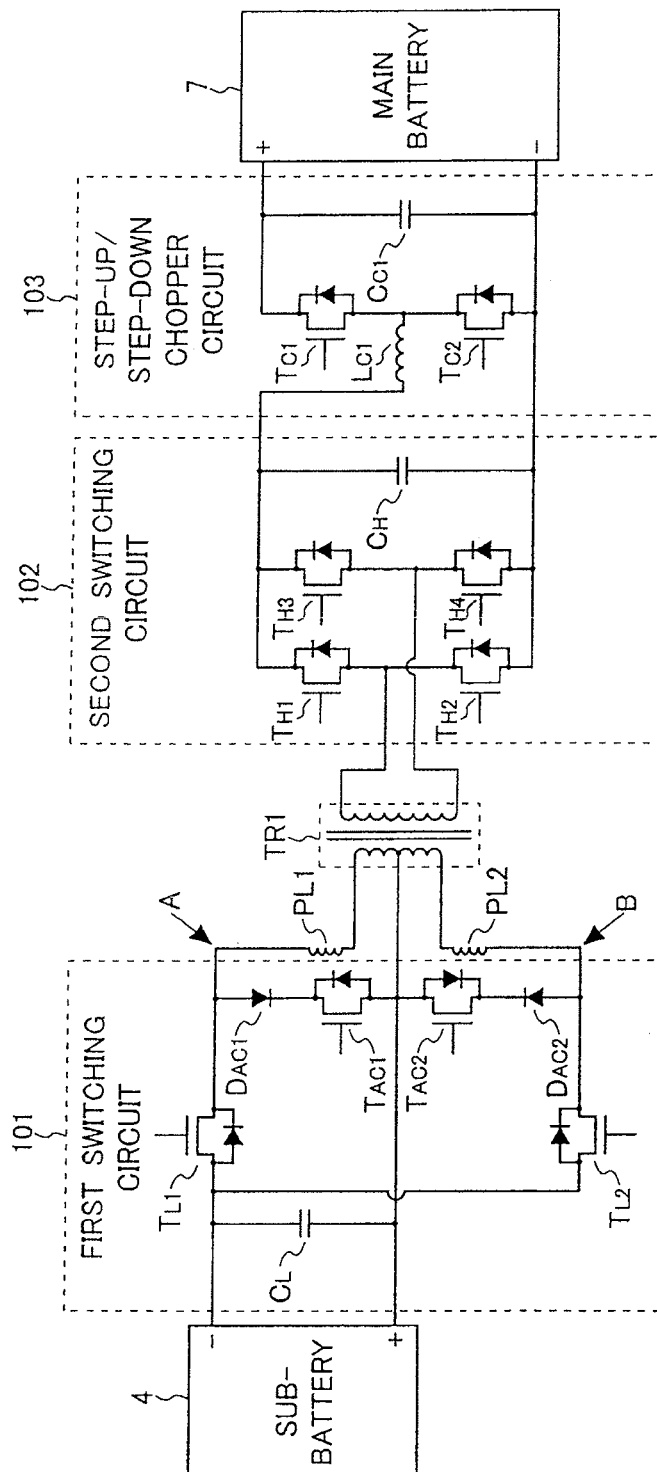


Fig. 11

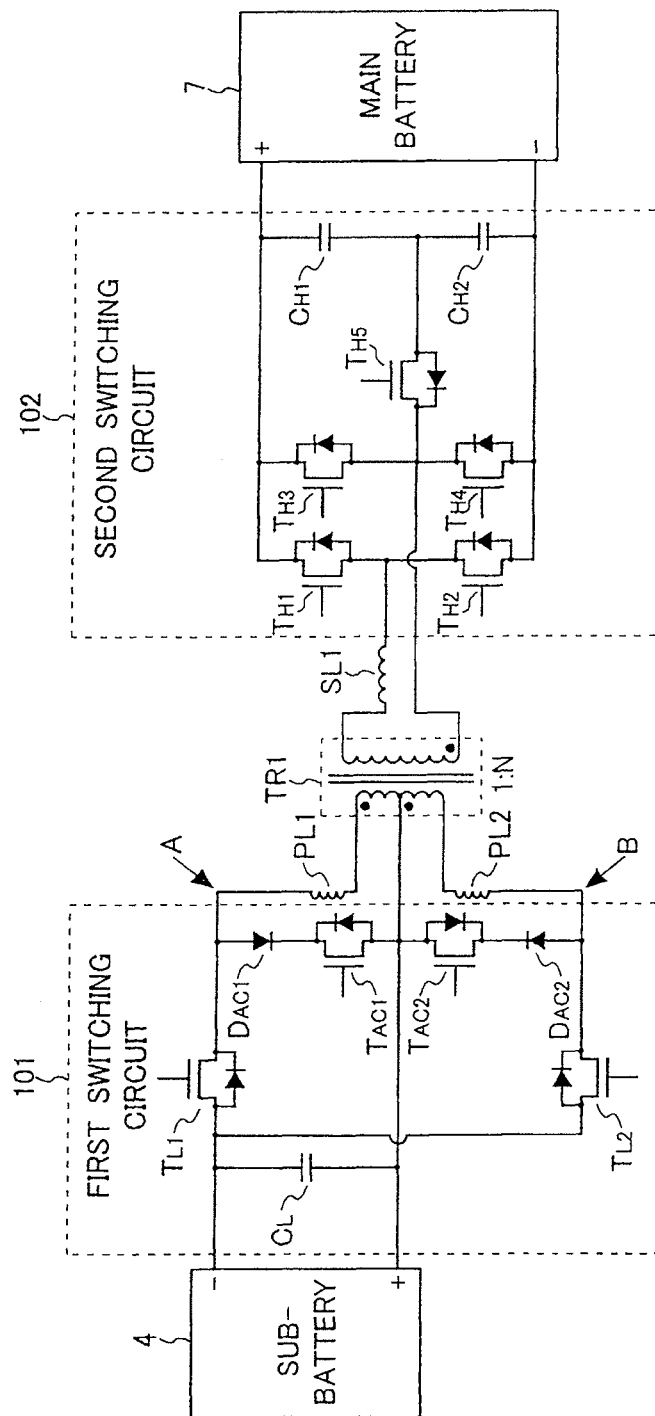


Fig. 12

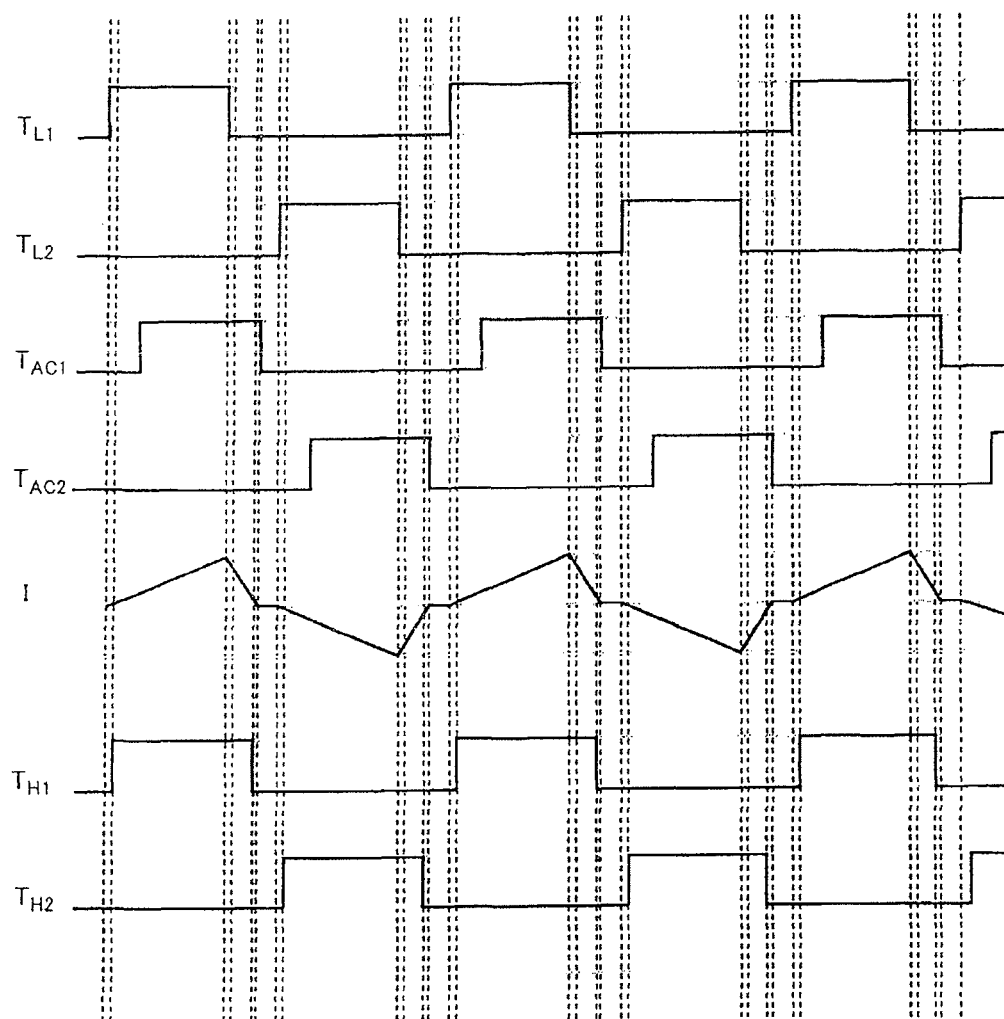


Fig. 13

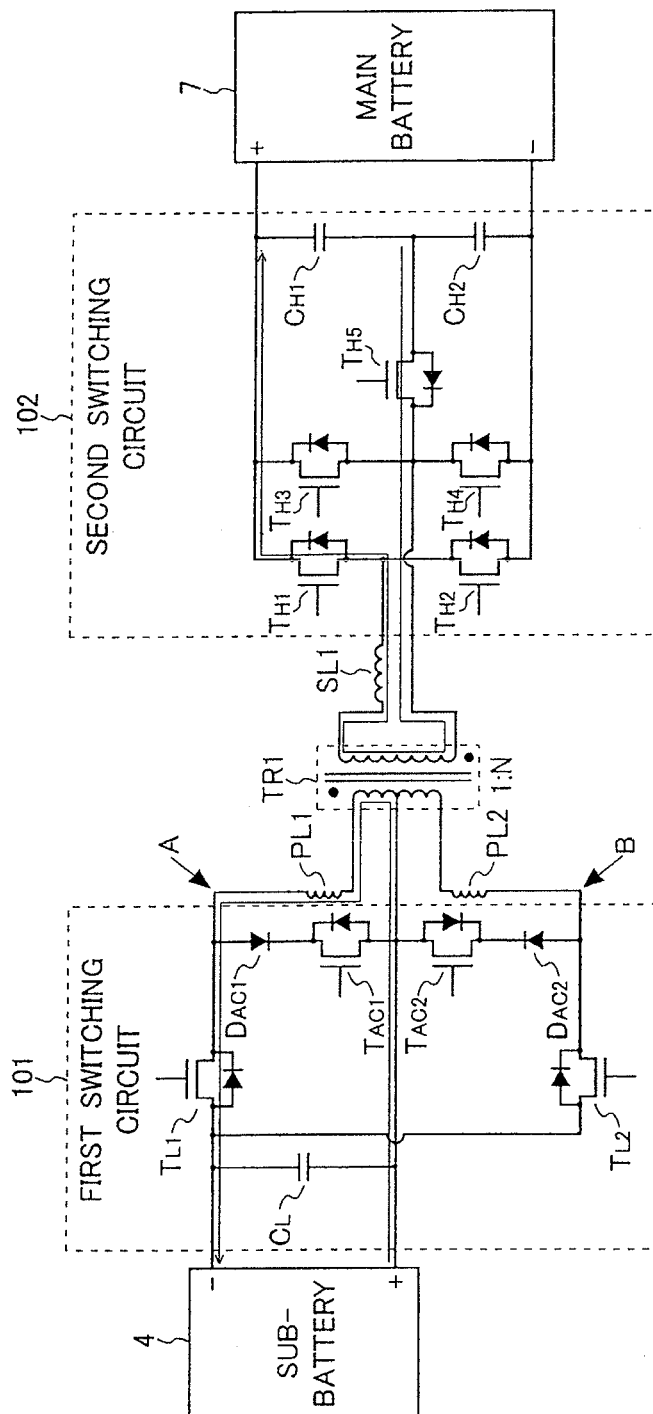


Fig. 14

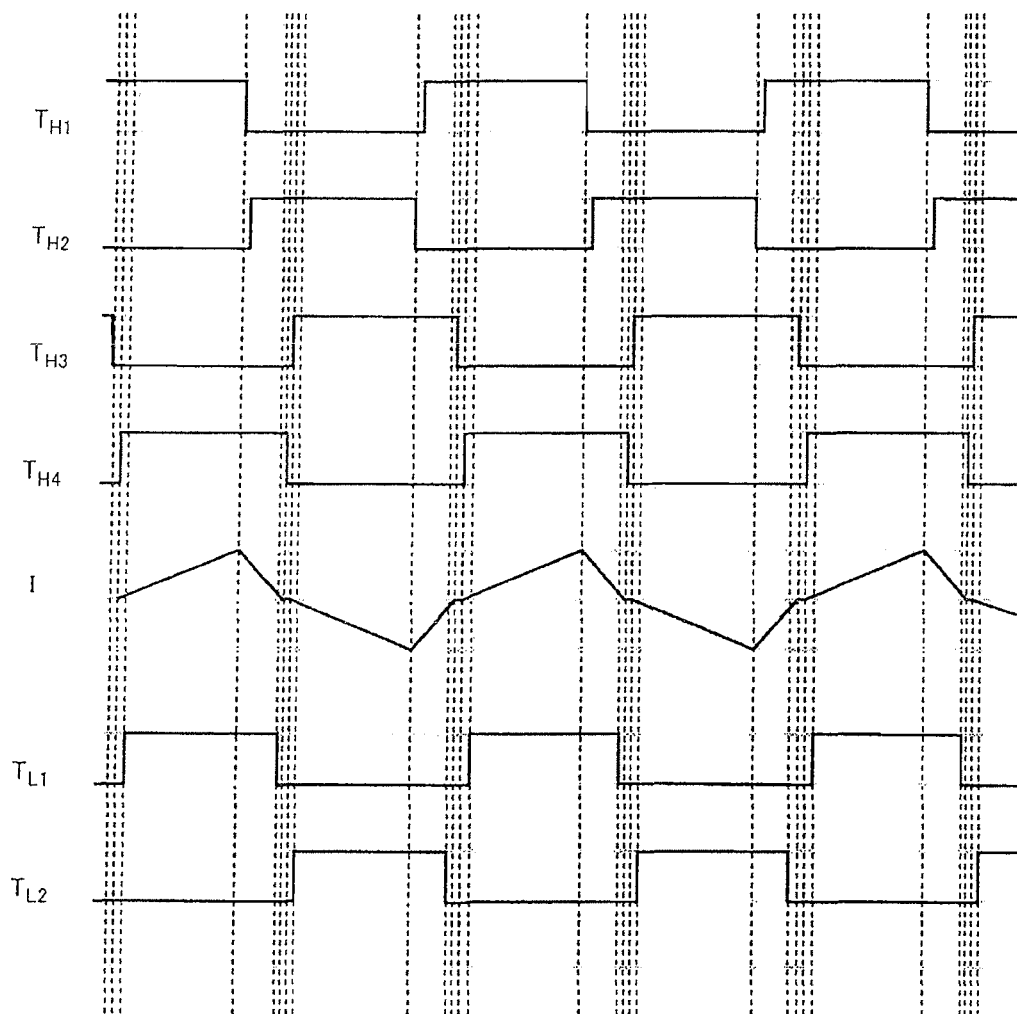


Fig. 15

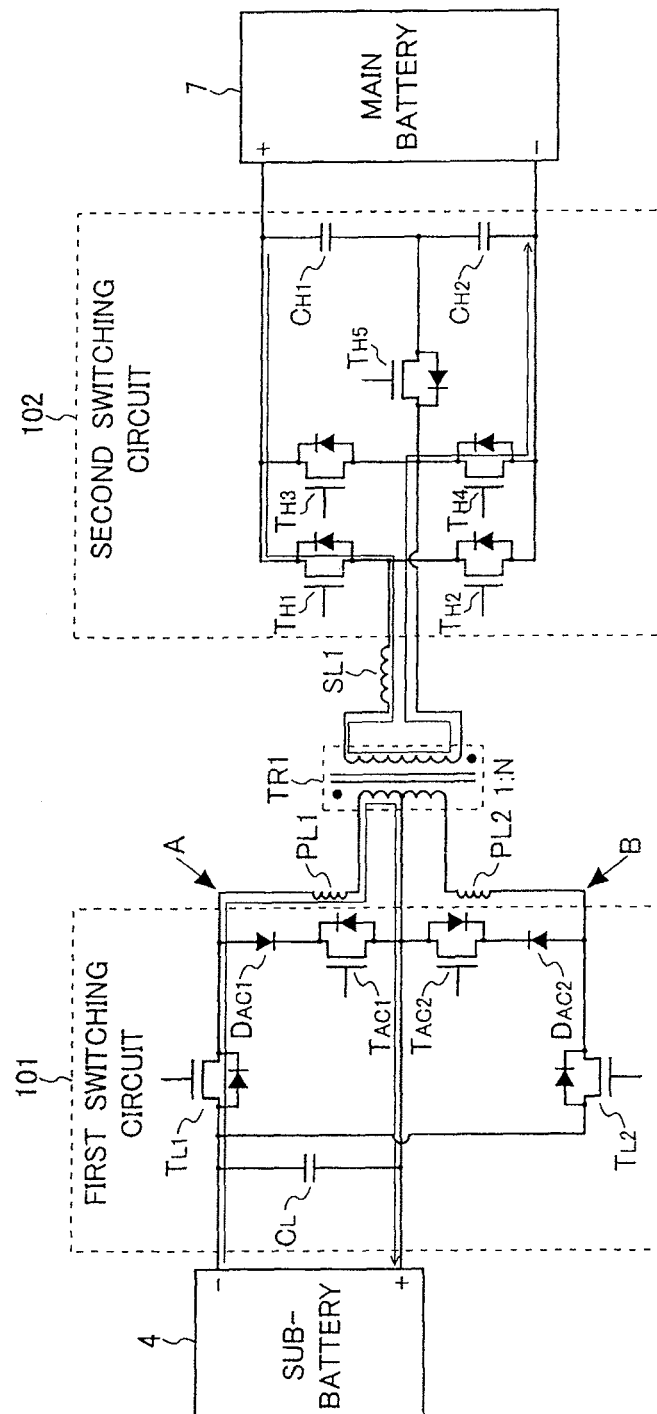
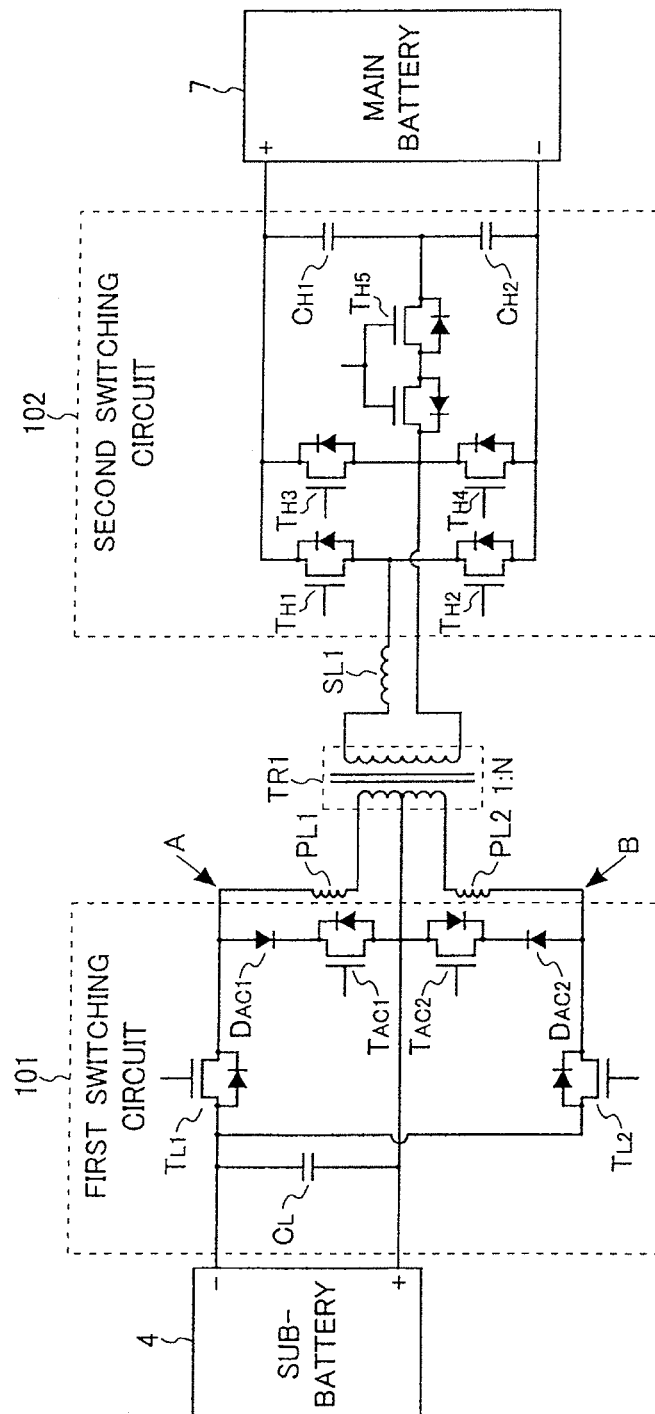


Fig. 16



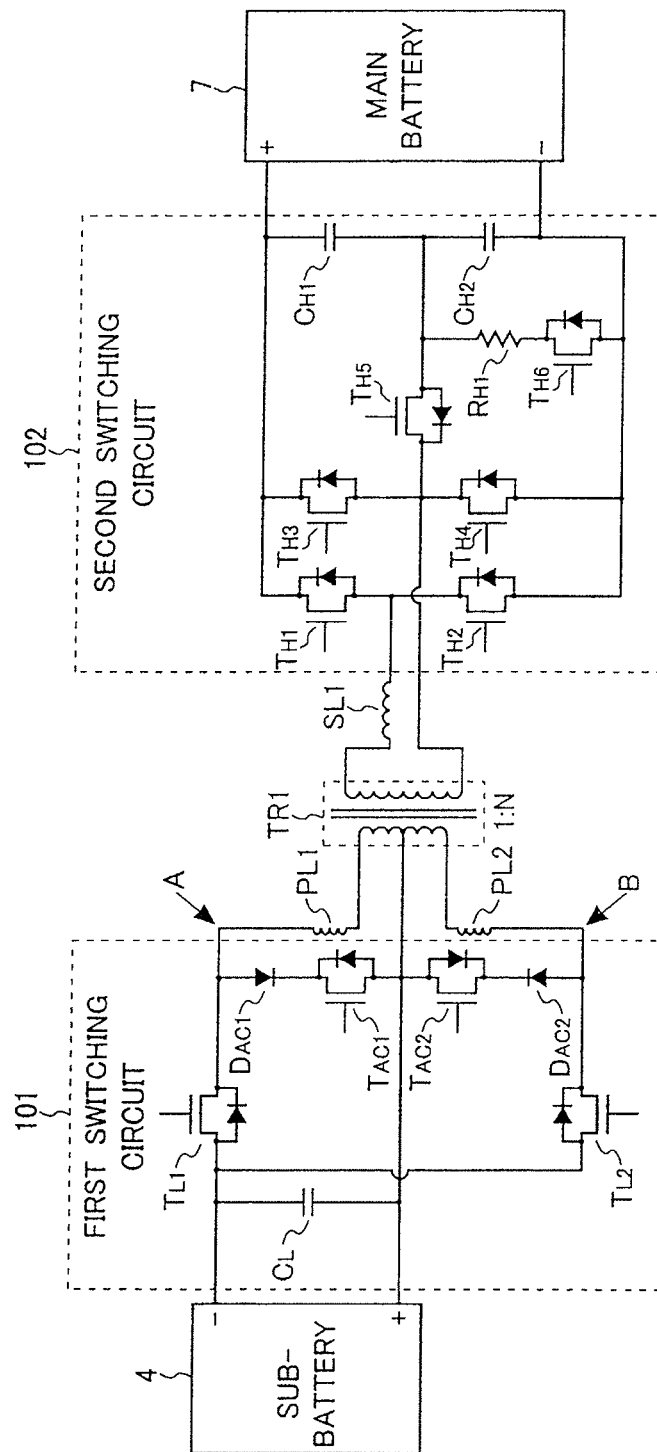
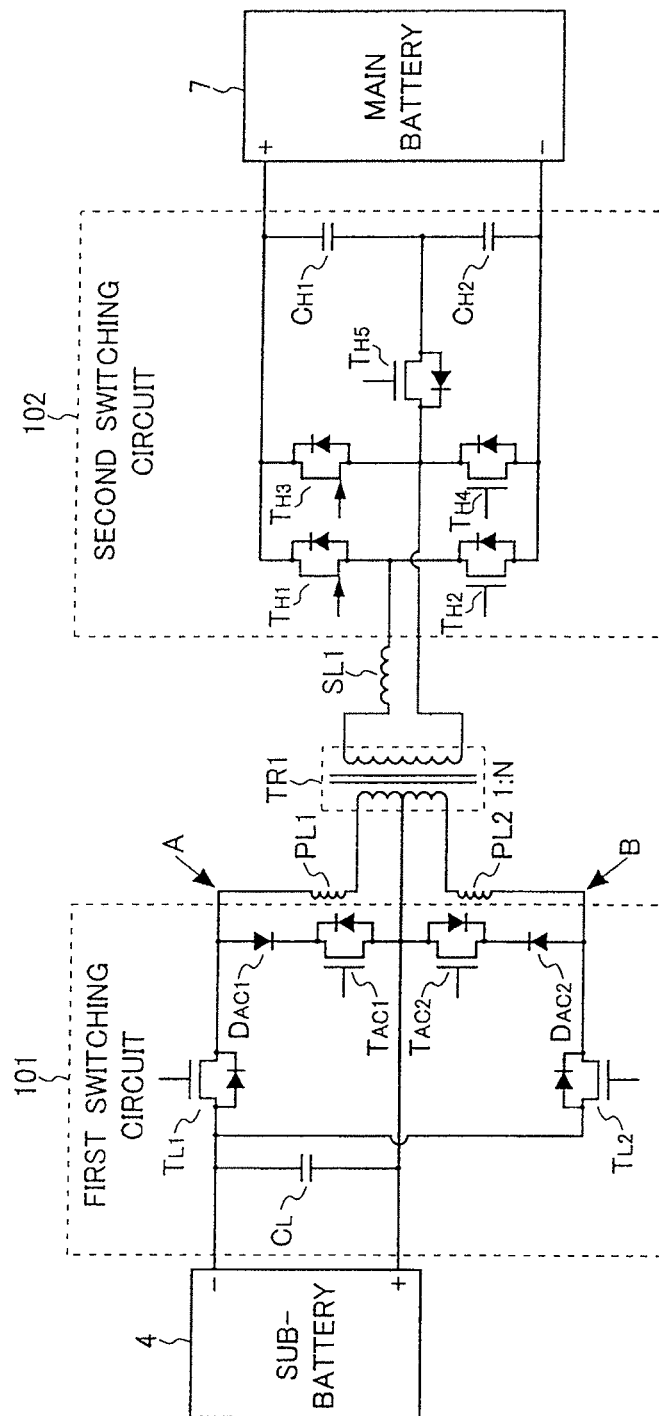
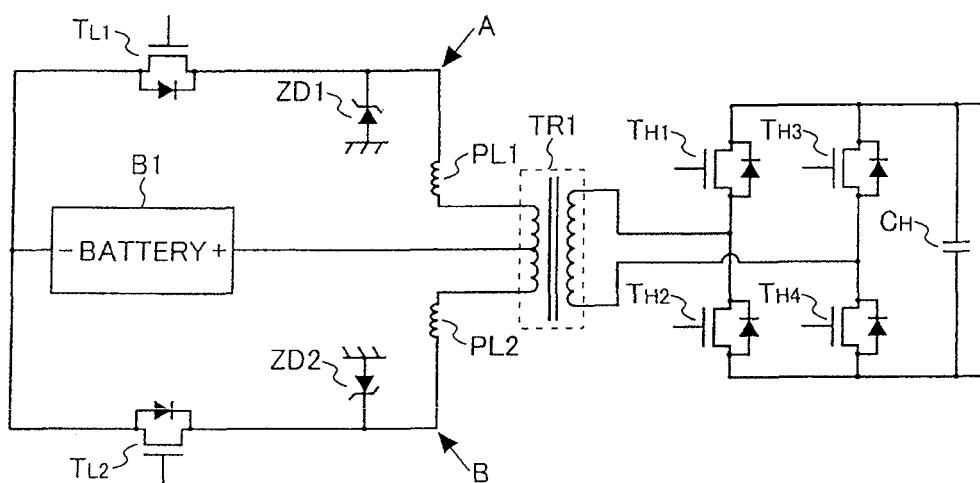


Fig. 17

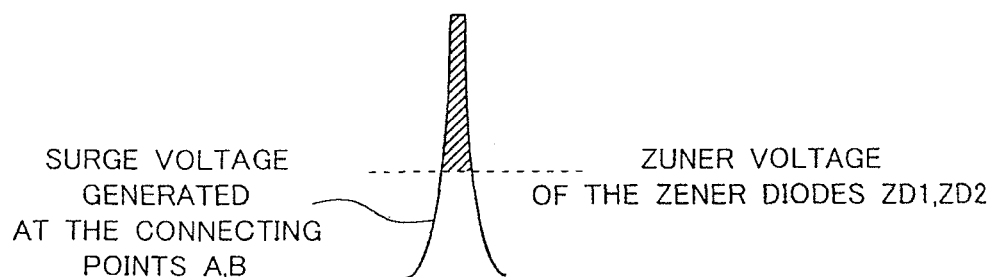
Fig. 18



RELATED ART
Fig. 20



RELATED ART
Fig. 21



PUSH-PULL CIRCUIT, DC/DC CONVERTER, SOLAR CHARGING SYSTEM, AND MOVABLE BODY

This non-provisional application claims priority under 35 U.S.C. §119(a) on Patent Application No. 2011-205536 filed in Japan on Sep. 21, 2011, the entire contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a push-pull circuit connected to an inductive load, and to a DC/DC converter, a solar charging system, and a movable body provided with the push-pull circuit.

2. Description of the Related Art

A push-pull circuit for converting DC voltage outputted from a DC power source into a pulse voltage is sometimes used in a power source device. For example, the power source device disclosed in Japanese Laid-open Patent Application No. 2000-50402 comprises a push-pull circuit **101**, a transformer **102**, a full-bridge circuit **103**, and a step-up chopper circuit provided between a capacitor **104** and a main battery **105**, as shown in FIG. 19.

The power source device disclosed in Japanese Laid-open Patent Application No. 2000-50402 cuts off a relay contact **106** when the main battery **105** is charged from an auxiliary equipment battery **100**, and performs a step-up operation via the push-pull circuit **101**, the transformer **102**, the full-bridge circuit **103** (used as a rectifier circuit), and the step-up chopper circuit. Also, the power source device disclosed in Japanese Laid-open Patent Application No. 2000-50402 allows conduction through the relay contact **106** when the auxiliary equipment battery **100** is charged from the main battery **105**, and performs a step-down operation via the full-bridge circuit **103**, the transformer **102**, and the push-pull circuit **101**.

The power supply device disclosed in Japanese Laid-open Patent Application No. 2000-50402 is limited to application in a hybrid electric automobile. Accordingly, in the power supply device disclosed in Japanese Laid-open Patent Application No. 2000-50402, the main application is to charge the auxiliary equipment battery **100** from the main battery **105**, and charging the main battery **105** from the auxiliary equipment battery **100** is mainly carried out for reverse transmission of electricity from the auxiliary equipment battery **100** to an engine startup motor when there is insufficient power in the main battery **105**. Therefore, the power supply device disclosed in Japanese Laid-open Patent Application No. 2000-50402 does not require high power transmission.

However, there is a need for higher-efficiency power transmission in accompaniment with higher capacity cells mounted in automobiles in recent years. A particular problem in electric automobiles is cruising distance, and a system that makes efficient use of electricity is essential.

Nevertheless, in the power supply device disclosed in Japanese Laid-open Patent Application No. 2000-50402, there is a problem in that power transmission between the main battery **105** and the auxiliary equipment battery **100** cannot be carried out efficiently.

In the case that a large current flows to the push-pull circuit **101** during a step-up operation, a very large surge voltage due to parasitic inductance (not shown in FIG. 19) of the transformer **102** is generated when a transistor **Q1** or **Q2** switches from an on state to an off state. This surge voltage is substantially proportional to the value of the electric current that flows to the transistor immediately prior to switching. There-

fore, the surge voltage increases in correspondence to a higher electric current flowing to the circuit, and the circuit is more readily destroyed. When Zener diodes **ZD1**, **ZD2** are provided in the manner shown in FIG. 20 in order to prevent the circuit from being destroyed by the surge voltage, there is a large loss that occurs when the surge component equal to or greater than the Zener voltage (the shaded portion of FIG. 21) is discarded to GND via the Zener diode **ZD1** in the case that the surge voltage is generated at a connection point A between the drain of the transistor T_{L1} , which is an N-channel metal oxide semiconductor field effect transistor (MOSFET), and one end of the low-voltage windings of the transformer **TR1**, and when the surge component equal to or greater than the Zener voltage (the shaded portion of FIG. 21) is discharged to GND via the Zener diode **ZD2** in the case that the surge voltage is generated at a connection point B between the drain of the transistor T_{L2} , which is an N-channel MOSFET, and one end of the low-voltage windings of the transformer **TR1**.

The battery **B1** of FIG. 20 corresponds to the auxiliary equipment battery **100** of FIG. 19. The transistor T_{L1} , which is the N-channel MOSFET of FIG. 20, corresponds to the transistor **Q1**, which is an NPN bipolar transistor, in FIG. 19, and the transistor T_{L2} , which is the N-channel MOSFET of FIG. 20, corresponds to the transistor **Q2**, which is an NPN bipolar transistor, in FIG. 19. The transformer **TR1** of FIG. 20 corresponds to the transformer **102** in FIG. 19. The transistors T_{H1} to T_{H4} , which are N-channel MOSFETs in FIG. 20, correspond to the transistors **Q3** to **Q6**, which are N-channel MOSFETs, in FIG. 19. The capacitor C_H of FIG. 20 corresponds to the capacitor **104** in FIG. 19. In FIG. 20, the parasitic inductance of the low-voltage windings of the transformer **TR1** is shown as parasitic inductors **PL1** and **PL2**.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a push-pull circuit capable of inhibiting surge voltage and increasing efficiency, and a DC/DC converter, a solar charging system, and a movable body provided with the push-pull circuit.

In order to achieve the object described above, the push-pull circuit according to an aspect of the present invention (first aspect) comprises:

- a first switching element having one end connected to one end of an inductive load and the other end connected to one end of a DC power source;

- a second switching element having one end connected to the other end of the inductive load and the other end connected to one end of the DC power source;

- a first rectifier element;

- a third switching element for switching a pathway between conductance and cutoff, the pathway leading from a connection point between one end of the first switching element and one end of the inductive load, via the first rectifier element, to a connection point between the other end of the DC power source and a center tap of the inductive load;

- a second rectifier element; and

- a fourth switching element for switching a pathway between conductance and cutoff, the pathway leading from a connection point between one end of the second switching element and the other end of the inductive load, via the second rectifier element, to a connection point between the other end of the DC power source and the center tap of the inductive load.

A push-pull circuit according to another aspect (second aspect) may be the push-pull circuit according to the first aspect, in which each of the first to fourth switching elements is switched ON or OFF so that the third switching element is

in an ON state when the first switching element switches from ON to OFF, and the third switching element is in an OFF state when the second switching element switches from OFF to ON; and the fourth switching element is in an ON state when the second switching element switches from ON to OFF, and the fourth switching element is in an OFF state when the first switching element switches from OFF to ON.

A push-pull circuit according to another aspect (third aspect) may be the push-pull circuit according to the first or second aspect, in which the third switching element and the fourth switching element are normally-off transistors; the push-pull circuit further comprising: a first power source circuit for generating voltage for setting one of the third switching element and the fourth switching element to ON, using the voltage of the connection point between one end of the first switching element and one end of the inductive load; and a second power source circuit for generating voltage for setting the other of the third switching element and the fourth switching element to ON, using the voltage of the connection point between one end of the second switching element and the other end of the inductive load.

A push-pull circuit according to another aspect (fourth aspect) may be the push-pull circuit according to the first or second aspect, in which the third switching element and the fourth switching element are normally-on transistors.

A push-pull circuit according to another aspect (fifth aspect) may be the push-pull circuit according to the first or second aspect, in which the third switching element and the fourth switching element are PNP bipolar transistors.

A push-pull circuit according to another aspect (sixth aspect) may be the push-pull circuit according to any of the first through fifth aspects, in which the first rectifier element and the second rectifier element are switching elements for synchronous rectification.

A push-pull circuit according to another aspect (seventh aspect) may be the push-pull circuit according to the sixth aspect, in which each of the first to fourth switching elements, the first rectifier element, and the second rectifier element is switched ON or OFF so that the first rectifier element switches from OFF to ON after the first switching element has switched from ON to OFF, and the first rectifier element switches from ON to OFF before the third switching element switches from ON to OFF; and the second rectifier element switches from OFF to ON after the second switching element has switched from ON to OFF, and the second rectifier element switches from ON to OFF before the fourth switching element switches from ON to OFF.

The DC/DC converter according to the present invention comprises a transformer and a push-pull circuit connected to the transformer, the push-pull circuit being the push-pull circuit according to any of the first to seventh aspects described above.

A solar charging system according to the present invention comprises: a solar cell; a first storage device for storing power outputted from the solar cell; a second storage device having greater storage capacity than the first storage device; and a DC/DC converter for DC/DC converting DC voltage outputted from the first storage device and feeding the converted voltage to the second storage device. The DC/DC converter of the configuration described above is preferably a bidirectional DC/DC converter that can perform DC/DC conversion in two directions.

The movable body according to the present invention comprises the solar charging system of the aspect described above.

In a preferred aspect of the movable body described above, the power outputted from the second storage device consti-

tuting the solar charging system is used as power for driving the movable body. It is furthermore preferred that the voltage of the second storage device be made greater than the voltage of the first storage device.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram showing the configuration of the push-pull circuit according to a first embodiment of the present invention;

FIG. 2 is a timing chart showing the timing for switching on and off the transistors of the push-pull circuit according to the first embodiment of the present invention;

FIG. 3 is a graph showing the results obtained by simulating the voltage of the connection point A and the voltage of the connection point B of the push-pull circuit according to the first embodiment of the present invention;

FIG. 4 is a graph showing the results obtained by simulating the voltage of the connection point A and the voltage of the connection point B of the push-pull circuit shown in FIG. 2;

FIG. 5 is a diagram showing a first example of the power source configuration of the driver for driving the transistors;

FIG. 6 is a diagram showing a second example of the power source configuration of the driver for driving the transistors;

FIG. 7 is a diagram showing the configuration of the push-pull circuit according to a second embodiment of the present invention;

FIG. 8 is a timing chart showing the timing for switching on and off the transistors of the push-pull circuit according to the second embodiment of the present invention;

FIG. 9 is a diagram showing an example of the overall configuration of a solar charging system for an electric automobile;

FIG. 10 is a diagram showing an example of a configuration of a DC/DC converter used in a solar charging system for an electric automobile;

FIG. 11 is a diagram showing the configuration of a bidirectional DC/DC converter according to a first advantageous configuration example;

FIG. 12 is a timing chart showing the timing for switching on and off the transistors of the bidirectional DC/DC converter according to the first advantageous configuration example in step-up operation;

FIG. 13 is a diagram showing the electric current pathway of the bidirectional DC/DC converter according to the first advantageous configuration example in step-up operation;

FIG. 14 is a timing chart showing the timing for switching on and off the transistors of the bidirectional DC/DC converter according to the first advantageous configuration example in step-down operation;

FIG. 15 is a diagram showing the electric current pathway of the bidirectional DC/DC converter according to the first advantageous configuration example in step-down operation;

FIG. 16 is a diagram showing the configuration of a bidirectional DC/DC converter according to a second advantageous configuration example;

FIG. 17 is a diagram showing the configuration of a bidirectional DC/DC converter according to a third advantageous configuration example;

FIG. 18 is a diagram showing the configuration of a bidirectional DC/DC converter according to a fourth advantageous configuration example;

FIG. 19 is a diagram showing the configuration of the power source device disclosed in Japanese Laid-open Patent Application No. 2000-50402;

FIG. 20 is a diagram showing a configuration example of a conventional push-pull circuit; and

FIG. 21 is a diagram showing the surge component discarded to GND in the case that a surge voltage occurs in the conventional push-pull circuit shown in FIG. 20.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Embodiments of the present invention are described below with reference to the drawings.

FIG. 1 is a diagram showing the configuration of the push-pull circuit according to a first embodiment of the present invention. The push-pull circuit according to the first embodiment of the present invention shown in FIG. 1 comprises: transistors T_{L1} and T_{L2} , which are N-channel MOSFETs; diodes D_{AC1} and D_{AC2} ; and transistors T_{AC1} and T_{AC2} , which are N-channel MOSFETs;

The drain of the transistor T_{L1} is connected to one end of the low-voltage winding of the transformer TR1, the drain of the transistor T_{L2} is connected to the other end of the low-voltage winding of the transformer TR1, and the source of the transistors T_{L1} and T_{L2} are connected to the negative pole of a battery B1. In FIG. 1, a parasitic inductance of the low-voltage winding transformer TR1 is shown as parasitic inductors PL1 and PL2. Diodes (hereinafter referred to as parallel diodes) are arranged in a row between the source and drain of the transistors, but the parallel diodes may be parasitic diodes (built-in diodes) of the transistors, or may be diodes externally connected in parallel, or another configuration.

The anode of a diode D_{AC1} is connected to the drain of the transistor T_{L1} , the cathode of the diode D_{AC1} is connected to the drain of a transistor T_{AC1} , and the source of the transistor T_{AC1} is connected to the positive pole of the battery B1 and to the center tap of the low-voltage winding of the transformer TR1. Similarly, the anode of a diode D_{AC2} is connected to the drain of the transistor T_{L2} , the cathode of the diode D_{AC2} is connected to the drain of a transistor T_{AC2} , and the source of the transistor T_{AC2} is connected to the positive pole of the battery B1 and to the center tap of the low-voltage winding of the transformer TR1.

A full-bridge circuit composed of transistors T_{H1} to T_{H4} , which are N-channel MOSFETs, is connected to the high-voltage winding of the transformer TR1, and a capacitor C_H is connected to the full-bridge circuit. In this way, the DC voltage outputted from the battery B1 can be stepped up via the pathway of the push-pull circuit according to the first embodiment of the present invention, the transformer TR1, and the full-bridge circuit described above and smoothed by the capacitor C_H ; and the voltage at the two ends of the capacitor C_H can be stepped down via the pathway of the full-bridge circuit described above, the transformer TR1, and the push-pull circuit according to the first embodiment of the present invention, and then fed to the battery B1.

In the push-pull circuit according to the first embodiment of the present invention shown in FIG. 1, the transistor T_{AC1} switches the conductance and cutoff of the pathway from the connecting point A between the drain of the transistor T_{L1} and one end of the low-voltage winding of the transformer TR1 to the connecting point between the positive pole of the battery B1 and the center tap of the low-voltage winding of the transformer TR1 via the diode D_{AC1} . When a surge component is generated by a parasitic inductor PL1 of the transformer TR1 when the pathway is conducting, the surge component flows back to the connecting point between the positive pole of the battery B1 and the center tap of the low-voltage winding of the transformer TR1 via the diode

D_{AC1} . Similarly, in the push-pull circuit according to the first embodiment of the present invention shown in FIG. 1, the transistor T_{AC2} switches the conductance and cutoff of the pathway from the connecting point B between the drain of the transistor T_{L2} and the other end of the low-voltage winding of the transformer TR1 to the connecting point between the positive pole of the battery B1 and the center tap of the low-voltage winding of the transformer TR1 via the diode D_{AC2} . When a surge component is generated by a parasitic inductor PL2 of the transformer TR1 when the pathway is conducting, the surge component flows back to the connecting point between the positive pole of the battery B1 and the center tap of the low-voltage winding of the transformer TR1 via the diode D_{AC2} .

Therefore, the transistor T_{AC1} must be in an ON state when the transistor T_{L1} switches from ON to OFF, the transistor T_{AC1} must be in OFF state when the transistor T_{L2} switches from OFF to ON, the transistor T_{AC2} must be in an ON state when the transistor T_{L2} switches from ON to OFF, the transistor T_{AC2} must be in OFF state when the transistor T_{L1} switches from OFF to ON. Accordingly, the ON and OFF switching of the transistors T_{L1} , T_{L2} , T_{AC1} , and T_{AC2} may be carried out with timing such as that shown in, e.g., FIG. 2. In the case that the ON and OFF switching of the transistors T_{L1} , T_{L2} , T_{AC1} , and T_{AC2} is carried out with timing such as that shown in FIG. 2, the control signal fed to the control terminal of the transistor T_{AC1} can be generated by merely delaying the control signal fed to the control terminal of the transistor T_{L1} , and the control signal fed to the control terminal of the transistor T_{AC2} can be generated merely by delaying the control signal fed to the control terminal of the transistor T_{L2} . Therefore, the control signal fed to the control terminal of the transistor T_{AC1} and the control signal fed to the control terminal of the transistor T_{AC2} are more readily generated.

Here, FIG. 3 shows the results obtained by simulating the voltage of the connecting point A and the voltage of the connecting point B of the push-pull circuit according to the first embodiment of the present invention shown in FIG. 1. Also, for comparison, FIG. 4 shows the results obtained by simulating the voltage of the connecting point A and the voltage of the connecting point B of the push-pull circuit shown in FIG. 20. In FIGS. 3 and 4, the thick line shows the voltage of the connecting point A and the narrow line shows the voltage of the connecting point B. In FIGS. 3 and 4, the voltage of the battery B1 is 12 V.

In accordance with the push-pull circuit according to the first embodiment of the present invention shown in FIG. 1, it is possible to considerably reduce the voltage step-up of the connecting point A brought about by the parasitic inductor PL1 of the transformer TR1 and the voltage step-up of the connecting point B brought about by the parasitic inductor PL2 of the transformer TR1. Accordingly, it is possible to prevent the voltages of the connecting points A and B from increasing beyond the withstand voltage of the transistors T_{L1} , T_{L2} and to prevent the transistors T_{L1} , T_{L2} from being destroyed. Also, in the push-pull circuit according to the first embodiment of the present invention shown in FIG. 1, the surge component produced by the parasitic inductors PL1 and PL2 of the transformer TR1 is not discarded to the exterior of the circuit, but is rather made to flow back through the electric current pathway: the connecting point A, the diode D_{AC1} , the transistor T_{AC1} , the center tap of the transformer TR1, the parasitic inductor PL1, and the connecting point A; or the pathway: the connecting point B, the diode D_{AC2} , the transistor T_{AC2} , the center tap of the transformer TR1, the parasitic inductor PL2, and the connecting point B. Therefore, the energy accumulated in the parasitic inductors PL1, PL2 can

be transferred to the high-voltage side (without being consumed by Zener diodes or the like), and loss can therefore be considerably reduced.

Next, an example of the power source configuration of the driver for driving the transistors T_{AC1} , T_{AC2} will be described.

FIG. 5 is a first example of the power source configuration of the driver for driving the transistors T_{AC1} , T_{AC2} . In FIG. 5, the same reference numerals are used for the same portions in FIG. 1, and a detailed description thereof is omitted. The voltage value described in FIG. 5 is an example.

In the first example shown in FIG. 5, the transistors T_{AC1} and T_{AC2} are each normally-off transistors. For example, in the case that the voltage of the battery B1 is 12 V, a gate driver DV1 for driving the transistor T_{AC1} requires a power source (e.g., a 24-V power source) having a voltage obtained by adding the voltage that exceeds the threshold voltage of the transistor T_{AC1} to the source voltage (e.g., 12 V) of the transistor T_{AC1} , and a gate driver DV2 for driving the transistor T_{AC2} requires a power source (e.g., a 24-V power source) having a voltage obtained by adding the voltage that exceeds the threshold voltage of the transistor T_{AC2} to the source voltage (e.g., 12 V) of the transistor T_{AC2} . In view of this fact, in the first example shown in FIG. 5, a power source (e.g., a 24-V power source) in which the drain voltage of the transistor T_{L1} is smoothed via a resistance R1 and a back flow-preventing diode D1 and furthermore by the capacitor C1 to obtain a DC voltage is connected to the gate driver DV1; and a power source (e.g., a 24-V power source) in which the drain voltage of the transistor T_{L2} is smoothed via a resistance R2 and a back flow-preventing diode D2 and furthermore by the capacitor C2 to obtain a DC voltage is connected to the gate driver DV2. Although not shown in the diagram, a power source (e.g., the source terminal of the transistor T_{AC1}) having a voltage for setting the transistor T_{AC1} to OFF is also connected to the gate driver DV1, and a power source (e.g., the source terminal of the transistor T_{AC2}) having a voltage for setting the transistor T_{AC2} to OFF is also connected to the gate driver DV2. It is also possible to connect to the gate driver DV2 a power source (e.g., a 24-V power source) for obtaining a DC voltage using the drain voltage of the transistor T_{L1} , and to connect to the gate driver DV1 a power source (e.g., a 24-V power source) for obtaining a DC voltage using the drain voltage of the transistor T_{L2} , which differs from the first example shown in FIG. 5. The reason that a power source voltage for driving such transistors T_{AC1} , T_{AC2} is that the drain voltage of the transistor T_{AC1} when the transistor T_{AC1} is OFF, and the drain voltage of the transistor T_{AC2} when the transistor T_{AC2} is OFF are about double (e.g., 24 V) the voltage (e.g., 12 V) of the battery B1, as shown in FIG. 3.

In accordance with such a power source configuration, a simple circuit configuration is achieved because there is no need to provide a special circuit for generating a voltage obtained by adding the voltage that exceeds the threshold voltage of the transistor T_{AC1} to the source voltage (e.g., 12 V) of the transistor T_{AC1} , (e.g., a circuit for stepping up the output voltage of the battery B1 to a double voltage); and a special circuit for generating a voltage obtained by adding the voltage that exceeds the threshold voltage of the transistor T_{AC2} to the source voltage (e.g., 12 V) of the transistor T_{AC2} , (e.g., a circuit for stepping up the output voltage of the battery B1 to a double voltage).

FIG. 6 shows a second example of the power source configuration of the driver for driving the transistors T_{AC1} and T_{AC2} . In FIG. 6, the same reference numerals are used for the same portions in FIG. 1, and a detailed description thereof is omitted. The voltage value described in FIG. 6 is an example.

In the second example shown in FIG. 6, the transistors T_{AC1} and T_{AC2} are each normally-on transistors. In this case, the gate driver DV3 for driving the transistor T_{AC1} does not require a power source having a greater voltage than the source voltage (e.g., 12 V) of the transistor T_{AC1} , and the gate driver DV4 for driving the transistor T_{AC2} does not require a power source having a greater voltage than the source voltage (e.g., 12 V) of the transistor T_{AC2} . In view of this fact, in the second example shown in FIG. 6, another control circuit power source (e.g., a 5-V power source) is connected to the gate drivers DV3 and DV4. In other words, another control circuit power source (e.g., a 5-V power source) is shared by other control circuits (e.g., drivers for driving other transistors, sensors, and the like) and the gate drivers DV3 and DV4. Although not shown in the drawing, a power source (e.g., a 12-V power source) having a voltage for setting the transistor T_{AC1} to ON is also connected to the gate driver DV3, and a power source (e.g., a 12-V power source) having a voltage for setting the transistor T_{AC2} to ON is also connected to the gate driver DV4.

In accordance with such a power source configuration, the number of components constituting the power source circuit can be reduced because a power source dedicated to the gate drivers DV3 and DV4 is not required to be provided. Also, loss can be further reduced in the second example shown in FIG. 6 by using a GaN-based transistor, a SiC-based transistor, or another compound transistor having an ON resistance that is less than a Si-based transistor, as the transistors T_{AC1} and T_{AC2} , which are normally-on transistors. In the case that a compound transistor is used as the transistors T_{AC1} and T_{AC2} , a built-in diode is not formed between the source and drain in the case of, e.g., a GaN-based transistor. Therefore, diodes may be connected in positions parallel to the transistors T_{AC1} and T_{AC2} in the same manner as FIG. 5, although the parallel diodes of the transistors T_{AC1} and T_{AC2} are not shown in FIG. 6.

Next, the push-pull circuit according to the second embodiment of the present invention will be described. FIG. 7 shows the configuration of the push-pull circuit according to the second embodiment of the present invention. In FIG. 7, other than changing the transistors T_{AC1} and T_{AC2} in FIG. 1 to transistors T_{AC1A} and T_{AC2A} in FIG. 7, the same reference numerals are used for the same portions in FIG. 1, and a detailed description thereof is omitted.

The push-pull circuit according to the second embodiment of the present invention shown in FIG. 7 has a configuration in which the transistors T_{AC1B} and T_{AC2B} for synchronous rectification are connected in parallel to the diodes D_{AC1} and D_{AC2} , respectively, of the push-pull circuit according to the first embodiment of the present invention shown in FIG. 1. However, the diodes D_{AC1} and D_{AC2} may be built-in diodes of the transistors T_{AC1B} and T_{AC2B} for synchronous rectification. It is possible to ensure even greater efficiency because loss attributable to the diode portion can be reduced by performing synchronous rectification.

In the push-pull circuit according to the second embodiment of the present invention shown in FIG. 7, the transistor T_{AC1B} must switch from OFF to ON after the transistor T_{L1} has switched from ON to OFF, the transistor T_{AC1B} must switch from ON to OFF before the transistor T_{AC1A} switches from ON to OFF, the transistor T_{AC2B} must switch from OFF to ON after the transistor T_{L2} has switched from ON to OFF, and the transistor T_{AC2B} must switch from ON to OFF before the transistor T_{AC2A} switches from ON to OFF. Accordingly, the ON and OFF switching of the transistors T_{L1} , T_{L2} , T_{AC1A} , T_{AC2A} , T_{AC1B} , and T_{AC2B} may be carried out with, e.g., timing such as that shown in FIG. 8.

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The example of the power source configuration of the driver for driving the transistors T_{AC1} and T_{AC2} in the push-pull circuit according to the second embodiment of the present invention shown in FIG. 7 is the same as the push-pull circuit according to the first embodiment of the present invention shown in FIG. 1, and a description thereof is omitted here.

The push-pull circuit according to the present invention can be applied to, e.g., a solar charging system for an electric automobile shown in FIG. 9.

The solar charging system for an electric automobile shown in FIG. 9 comprises a solar panel 1 in which a plurality of solar cells are arranged, a maximum power point tracking (MPPT) controller 2 for controlling the output voltage of the solar panel 1 so that the output voltage of the solar panel 1 is maximized, a control circuit 3 for managing and controlling a sub-battery 4, a sub-battery 4 for storing the output power of the solar panel 1, a DC/DC converter 5 for converting DC voltage outputted from the sub-battery 4 to DC voltage fed to the main battery 7, a control circuit 6 for managing and controlling the main battery 7, and a main battery 7 having a greater capacity than the sub-battery 4. Although not shown in FIG. 9, a circuit for generating control signals for controlling the ON/OFF switching of the switching elements in the DC/DC converter 5 is also provided inside the electric automobile.

In the case that the push-pull circuit according to the present invention is applied to the solar charging system for an electric automobile shown in FIG. 9, the DC/DC converter 5 can be designed to have the push-pull circuit according to the present invention.

An inverter 8 provided to the electric automobile converts DC voltage outputted from the main battery 7 into motor-driving AC voltage. A motor 9 provided to the electric automobile is rotatably driven by the motor-driving AC voltage outputted from the inverter 8. The drive wheels of the electric automobile are rotated by the rotation of the motor 9. Regenerative energy generated by the motor 9 during braking of the electric automobile is recovered by the control circuit 6 and stored in the main battery 7. Also, the DC voltage outputted from the sub-battery 4 is also used as a power source for headlights and the like.

In FIG. 9, the solar charging system provided with the push-pull circuit according to the present invention is a solar charging system for an electric automobile, but may also be used as a solar charging system for other movable bodies (e.g., a motorcycle, or the like).

Next, an example of the configuration of the DC/DC converter 5 will be described.

FIG. 10 shows an example of the configuration of the DC/DC converter 5. In the configuration example shown in FIG. 10, the DC/DC converter 5 comprises a first switching circuit 101, a transformer TR1, a second switching circuit 102, and a step-up/step-down chopper circuit 103. The arrangement of the DC/DC converter composed of the first switching circuit 101, the transformer TR1, and the second switching circuit 102, and the DC/DC converter composed of the step-up/step-down chopper circuit 103 may be reversed. Also, in order to constantly maintain high efficiency in accordance with the various states of the voltages of the sub-battery 4 and the main battery 7, it is preferred that the DC/DC converter composed of the first switching circuit 101, the transformer TR1, and the second switching circuit 102 be made to operate on the basis of a fixed duty, and that the DC/DC converter composed of the step-up/step-down chopper circuit 103 be made to operate on the basis of a variable duty, to control the step up/step down voltage ratio, whereby

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the DC/DC converter 5 can be made into a variable factor DC/DC converter for controlling the conversion factor using the duty of the step-up/step-down chopper circuit 103. However, it is possible to exclude the step-up/step-down chopper circuit 103 and to use only a DC/DC converter composed of the first switching circuit 101, the transformer TR1, and the second switching circuit 102.

The step-up/step-down chopper circuit 103 is composed of transistors T_{C1} and T_{C2} , which are N-channel MOSFETs, an inductor L_{C1} , and a capacitor C_{C1} . The transistor T_{C1} operates as a synchronous rectifier element when charging is carried out from the sub-battery 4 to the main battery 7, and the transistor T_{C2} operates as a synchronous rectifier element when charging is carried out from the main battery 7 to the sub-battery 4. However, it is possible to keep the synchronous rectifier elements in an OFF state and operate only the diodes connected in parallel (parasitic) with the synchronous rectifier elements.

The first switching circuit 101 is composed of the push-pull circuit according to the present invention, and a capacitor C_L , which functions as a smoothing capacitor when charging from the main battery 7 to the sub-battery 4. In FIG. 10, the push-pull circuit of the first embodiment of the present invention is shown as the push-pull circuit according to the present invention, but it is also possible to use another push-pull circuit according to the present invention.

Described below is a advantageous configuration example of a bidirectional converter composed of the first switching circuit 101, the transformer TR1, and the second switching circuit 102.

FIG. 11 is a diagram showing the configuration of a bidirectional DC/DC converter according to a first advantageous configuration example. The bidirectional DC/DC converter according to the first advantageous configuration example shown in FIG. 11 comprises: a first switching circuit 101; a transformer TR1 having a winding ratio (the winding ratio between the low-voltage winding and the high-voltage winding) of 1:N; a full-bridge circuit connected to the high-voltage winding of the transformer TR1, the full-bridge circuit being composed of transistors T_{H1} to T_{H4} , which are N-channel MOSFETs; and a second switching circuit 102 having a transistor T_{H5} , which is an N-channel MOSFET, and capacitors C_{H1} and C_{H2} , provided between the full-bridge circuit and the main battery 7.

The source of the transistor T_{H1} and the drain of the transistor T_{H2} are connected to one end of the high-voltage winding of the transformer TR1; and the source of the transistor T_{H3} , the drain of the transistor T_{H4} , and the drain of the transistor T_{H5} are connected to the other end of the high-voltage winding of the transformer TR1. The drain of the transistor T_{H1} and the drain of the transistor T_{H3} , and one end of the capacitor C_{H1} are connected to the positive pole of the main battery 7; and the source of the transistor T_{H2} and the source of the transistor T_{H4} , and one end of the capacitor C_{H2} are connected to the negative pole of the main battery 7. The other end of the capacitor C_{H1} and the other end of the capacitor C_{H2} are connected to the source of the transistor T_{H5} . The diodes between the source and drain of the transistors are parallel transistors. The main battery 7 is a battery having higher voltage than the sub-battery 4. Also, the inductors PL1, PL2, SL1 are parasitic inductors of the transformer TR1. However, the inductor SL1 may include an external inductor (other than the parasitic inductors of the transformer TR1) connected to the transformer TR1. In this case, the control range of the output voltage can be varied by adjusting the inductance of the inductor SL1. Similarly, the control range of the output voltage can be varied by connecting the external

inductor to the inductors PL1, PL2, but such is not preferred in that there is a further increase in the energy of the surge generated when the transistors T_{L1} , T_{L2} are set to OFF. On the other hand, the electric current that flows through the inductor SL1 positioned on the high-voltage side is less subject to the surge because the electric current becomes relatively low. In other words, in the case that an inductor is added in order vary the control range of the output voltage, the inductor is preferably added to the inductor SL1.

The bidirectional DC/DC converter according to the first advantageous configuration example shown in FIG. 11 carries out DC/DC conversion by keeping the transistor T_{H5} constantly ON during step-up operation, converting the DC voltage outputted from the sub-battery 4 into AC voltage using the first switching circuit 101, stepping up the voltage using the transformer TR1, and then performing rectification using the voltage-doubling rectification circuit composed of the transistors T_{H1} and T_{H2} , the transistor T_{H3} , and the capacitors C_{H1} and C_{H2} . Since the winding ratio (the winding ratio between the low-voltage winding and the high-voltage winding) of the transformer TR1 is 1:N, the fixed step-up factor in the bidirectional DC/DC converter according to the first advantageous configuration example is a factor of 2N (excluding the voltage change brought about by the inductors PL1, PL2, SL1). The duty of the gate-driving voltage of the transistors T_{L1} and T_{L2} is varied, whereby the rate of variation (di/dt ; >0) of the electric current i that flows to the parasitic inductors is made to vary, and the output voltage and output electric current can be controlled.

The bidirectional DC/DC converter according to the first advantageous configuration example shown in FIG. 11 carries out DC/DC conversion by keeping the transistor T_{H5} constantly OFF during step-down operation, converting the DC voltage outputted from the main battery 7 into AC voltage using the second switching circuit 102, stepping down the voltage using the transformer TR1, performing rectification using the transistors T_{L1} and T_{L2} , and then feeds the DC/DC-converted voltage to the sub-battery 4. Since the winding ratio (winding ratio between the high-voltage winding and the low-voltage winding) of the transformer TR1 is 1:N, the fixed step-down factor in the bidirectional DC/DC converter according to the first advantageous configuration example is a factor of 1/N (excluding the effect of the parasitic inductors). The duty of the gate-driving voltage of the transistors T_{H1} , T_{H2} , T_{H3} , T_{H4} is varied, whereby the rate of variation (di/dt ; >0) of the electric current i that flows to the parasitic inductors is made to vary, and the output voltage and output electric current can be controlled.

The reason that the fixed step-up factor of the bidirectional DC/DC converter according to the preferred configuration is greater than the inverse of the fixed step-down factor is next described.

For example, let V_{sub} be the voltage of the sub-battery 4, V_{sub_min} (minimum) to V_{sub_max} (maximum) be the voltage range thereof, V_{main} be the voltage of the main battery 7, V_{main_min} (minimum) to V_{main_max} (maximum) be the voltage range thereof, α be the fixed step-up factor that does not depend on the duty determined by the low-voltage winding, the high-voltage winding, and the like of the transformer, $1/\beta$ be the fixed step-down factor that does not depend on the duty determined by the winding ratio and the like of the transformer, L be the inductance (disposed on the high-voltage side of the transformer) equivalent to the entire parasitic inductance of the transformer (including external inductance connected to the transformer), and I be the electric current that flows to the high-voltage winding of the transformer.

In this case, the expression $V_{main} = \alpha V_{sub} - L(di/dt)$ holds true in the step-up operation. Since switching loss is reduced, the ratio (di/dt) is a positive value when one of the transistors T_{L1} , T_{L2} is in an ON state in the case that the switching of the

transistors T_{L1} , T_{L2} is set to zero electric current switching (or switching at an electric current value that is sufficiently low). Therefore, the expression $V_{main} = \alpha V_{sub} - L(di/dt) < \alpha V_{sub}$ holds true. The fixed step-up factor (e.g., the winding ratio of the transformer) must be selected so that

$$V_{main_max} < \alpha V_{sub_min} \quad (\text{Formula 1})$$

with consideration given to the voltage ranges of the sub-battery 4 and the main battery 7.

Next, the expression $V_{sub} = (1/\beta) \{V_{main} - L(di/dt)\}$ holds true in the step-down operation. The ratio (di/dt) is a positive value when the transistors T_{H1} and T_{H4} are in an ON state (OFF state) and the transistors T_{H2} , T_{H3} are in an OFF state (ON state) in the case that, among the switching of the transistors T_{H1} , T_{H2} , T_{H3} , T_{H4} , the switching for inverting the direction of the voltage generated between the transformer terminals is set to zero electric current switching (or switching at an electric current value that is sufficiently low) for the purpose of reducing switching loss. Therefore, the expression $V_{sub} = (1/\beta) \{V_{main} - L(di/dt)\} < (1/\beta) V_{main}$ holds true. The fixed step-down factor (e.g., the winding ratio of the transformer) must be selected so that

$$V_{sub_max} < (1/\beta) V_{main_min} \quad (\text{Formula 2})$$

with consideration given to the voltage ranges of the sub-battery 4 and the main battery 7.

In the bidirectional DC/DC converter, the formulas 1 and 2 must be simultaneously satisfied. Therefore, the following holds true from the formulas 1 and 2,

$$V_{sub_max} < (1/\beta) V_{main_min} < (\alpha/\beta) V_{sub_min} \therefore (\alpha/\beta) > (V_{sub_max}/V_{sub_min}) > 1 \quad (\text{Formula 3}).$$

Therefore, the winding ratio of the transformer during step-up is $1:\alpha$, the winding ratio of the transformer during step-down is $1:\beta$ ($<\alpha$), and winding ratios that are different during step-up and during step-down must be used when the fixed step-up factor α and the fixed step-down factor ($1/\beta$) are determined only by the winding ratio of the transformer, making the circuit configuration very complicated. On the other hand, in the circuit of FIG. 11, the winding ratio of the transformer TR1 is 1:N, which accordingly corresponds to the case in which $\alpha=2N$ and $\beta=N$, and Formula 3 is satisfied. In other words, in the circuit of FIG. 11, the winding ratio of the transformer is not required to be changed during step-up and during step-down. It is therefore possible to configure a bidirectional DC/DC converter using a simple circuit configuration.

Next, FIG. 12 shows a timing chart of the timing of the ON, OFF switching of the transistors of the bidirectional DC/DC converter according to the first advantageous configuration example during step-up operation. The transistors T_{H3} , T_{H4} are constantly OFF, and the transistor T_{H5} is constantly ON.

(U-1) When the transistor T_{L1} is set to ON and the voltage of the sub-battery 4 is applied to the low-voltage winding of the transformer TR1, an electromotive force is generated in the high-voltage winding of the transformer TR1 and an electric current flows through the transistor T_{H5} and the transistor T_{H1} (see FIG. 13). At this time, the transistor T_{H1} is set to ON in conjunction with the timing at which the electric current flows to the parallel diode of the transistor T_{H1} , and synchronous rectification is performed, thereby making it possible to reduce loss attributable to the diode portion. In this case, the transistor T_{H1} is preferably set to ON after the transistor T_{L1} has been set to ON.

(U-2) Next, the transistor T_{AC1} is set to ON.

(U-3) Next, the transistor T_{L1} is set to OFF. At this time, the electric potential of the connecting point A increases due to the electromotive force generated in the parasitic inductors PL1 and SL1 of the transformer TR1, and a return electric current flows via the pathway: the transformer TR1, the

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inductor PL1, the connecting point A, the diode D_{AC1} , the transistor T_{AC1} , and the transformer TR1. The energy accumulated in the inductors PL1 and SL1 is transferred to the capacitor C_{H1} or the main battery 7 without an excessive surge voltage being generated. Therefore, it is possible to obtain high efficiency while circuit destruction is prevented.

(U-4) Next, the transistor T_{H1} is set to OFF with timing at which the return electric current is zero or sufficiently low, and the transistor T_{AC1} is subsequently set to OFF.

(U-5) Next, the direction of the voltage between the terminals of the transformer TR1 is inverted, after which the transistor T_{L2} is set to ON and the voltage of the sub-battery 4 is applied to the low-voltage winding of the transformer TR1, whereupon an electromotive force is generated in the high-voltage winding of the transformer TR1 and electric current flows through the transistors T_{H5} and T_{H2} (see FIG. 13). At this time, the transistor T_{H2} is set to ON in conjunction with the timing at which the electric current flows to the parallel diode of the transistor T_{H2} , and synchronous rectification is performed, thereby making it possible to reduce loss attributable to the diode portion. In this case, the transistor T_{H2} is preferably set to ON after the transistor T_{L2} has been set to ON.

(U-6) Next, the transistor T_{AC2} is set to ON.

(U-7) Next, the transistor T_{L2} is set to OFF. At this time, the electric potential of the connecting point B increases due to the electromotive force generated in the parasitic inductors PL2 and SL1 of the transformer TR1, and a return electric current flows via the pathway: the transformer TR1, the inductor PL2, the connecting point B, the diode D_{AC2} , the transistor T_{AC2} , and the transformer TR1. The energy accumulated in the inductors PL2 and SL1 is transferred to the capacitor C_{H2} without an excessive surge voltage being generated. Therefore, it is possible to obtain high efficiency while circuit destruction is prevented.

(U-8) Next, the transistor T_{H2} is set to OFF with timing at which the return electric current is zero or sufficiently low, and the transistor T_{AC2} is subsequently set to OFF.

(U-1) to (U-8) described above are thereafter repeated.

Next, FIG. 14 shows a timing chart of the timing of the ON, OFF switching of the transistors of the bidirectional DC/DC converter according to the first advantageous configuration example during step-down operation. The transistor T_{H5} is constantly OFF.

(D-1) When the transistor T_{H1} is set to ON with the transistor T_{H4} in an ON state, and the voltage of the main battery 7 is applied to the high-voltage winding of the transformer TR1, an electromotive force is generated in the low-voltage winding of the transformer TR1 and an electric current flows through the transistor T_{L1} (see FIG. 15). At this time, the transistor T_{L1} is set to ON in conjunction with the timing at which the electric current flows to the parallel diode of the transistor T_{L1} , and synchronous rectification is performed, thereby making it possible to reduce loss attributable to the diode portion.

(D-2) Next, the transistor T_{H4} is set to OFF, and the transistor T_{H3} is subsequently set to ON, whereby electric current is made to flow back via the pathway: the transistor T_{H1} , the transformer TR1, the transistor T_{H3} , and the transistor T_{H1} . The energy accumulated in the parasitic inductors of the transformer TR1 is thereby transferred to the low-voltage side (sub-battery 4). Electric current flows to the parallel diode of the transistor T_{H3} in the period of time from the transistor T_{H4} being set to OFF to the transistor T_{H3} being set to ON.

(D-3) Next, the transistor T_{L1} and the transistor T_{H1} are set to OFF with timing at which the return electric current has become zero or sufficiently low (ZCS: zero electric current

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switching). The transistor T_{L1} is preferably set to OFF before the transistor T_{H1} is set to OFF.

(D-4) Thereafter, the direction of the voltage between the terminals of the transformer TR1 is inverted, after which the transistor T_{H2} is set to ON (ZVS: zero voltage switching) and the voltage of the main battery 7 is applied to the high-voltage winding of the transformer TR1, whereby an electromotive force is generated in the low-voltage winding of the transformer TR1 and electric current flows through the transistor T_{L2} (or the parallel diode). At this time, the transistor T_{L2} is set to ON in conjunction with the timing at which the electric current flows to the parallel diode of the transistor T_{L2} (ZVS), and synchronous rectification is performed, whereby loss attributable to the diode portion is reduced. In this case, the transistor T_{L2} is preferably set to ON after the transistor T_{H2} has been set to ON.

(D-5) Next, the transistor T_{H3} is set to OFF (ZVS), and the transistor T_{H4} is subsequently set to ON (ZVS), whereby the electric current flows via the pathway: the transistor T_{H2} , the transformer TR1, the transistor T_{H4} , and the transistor T_{H2} . The energy accumulated in the parasitic inductors of the transformer TR1 is thereby transferred to the low-voltage side. Electric current flows to the parallel diode of the transistor T_{H4} in the period of time from the transistor T_{H3} being set to OFF to the transistor T_{H4} being set to ON.

(D-6) Next, the transistor T_{L2} and the transistor T_{H2} are set to OFF with timing at which the return electric current has become zero or sufficiently low (ZCS). The transistor T_{L2} is preferably set to OFF before the transistor T_{H2} is set to OFF.

(D-7) Thereafter, the direction of the voltage between the terminals of the transformer TR1 is inverted, after which the transistor T_{H1} is set to ON (ZVS) and the voltage of the main battery 7 is applied to the high-voltage winding of the transformer TR1, whereby an electromotive force is generated in the low-voltage winding of the transformer TR1 and electric current flows through the transistor T_{L1} (or the parallel diode). At this time, the transistor T_{L1} is set to ON (ZVS) in conjunction with the timing at which the electric current flows to the parallel diode of the transistor T_{L1} , and synchronous rectification is performed, whereby loss attributable to the diode portion is reduced. In this case, the transistor T_{L1} is preferably set to ON after the transistor T_{H1} has been set to ON.

(D-2) to (D-8) described above are thereafter repeated.

All switching is ZVS or ZCS soft switching, and loss can be reduced while the occurrence of surge voltage or the like is inhibited.

The interval in which the transistors T_{H1} and T_{H4} are set to ON, and the interval in which the transistors T_{H2} and T_{H3} are set to ON are repeated in alternating fashion, but a large short-circuit electric current flows when the transistors T_{H1} and T_{H2} are simultaneously set to ON, and a large short-circuit electric current flows when the transistors T_{H3} and T_{H4} are simultaneously set to ON. Therefore, an interval (dead time) in which the transistors T_{H1} to T_{H4} are set to OFF is provided in order to prevent the transistors T_{H1} and T_{H2} from being simultaneously ON and the transistors T_{H3} and T_{H4} from being simultaneously ON. It is thereby possible to ensure even greater efficiency.

In the case that the transistor T_{H5} is configured using a single MOS transistor in the same manner as the bidirectional DC/DC converter according to the first advantageous configuration example, the capacitor C_{H2} short circuits via the transistor T_{H4} and the built-in diode of the transistor T_{H5} ; a large short-circuit electric current flows; and the capacitor C_{H2} , the transistor T_{H4} , and the transistor T_{H5} are damaged

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when the transistor T_{H4} has been set to ON in a state in which the capacitor C_{H2} has been charged during, e.g., the start of step-down operation.

In view of the above, preferably used is a configuration of, e.g., the bidirectional DC/DC converter according to a second advantageous configuration example shown in FIG. 16; or the bidirectional DC/DC converter according to a third advantageous configuration example shown in FIG. 17. In FIGS. 16 and 17, the same reference numerals are used for the same portions in FIG. 11, and a detailed description thereof is omitted.

In the bidirectional DC/DC converter according to the second advantageous configuration example shown in FIG. 16, the transistor T_{H5} is composed of two N-channel MOSFETs in which the sources are connected to each other and a shared gate control signal is fed to the gates. The capacitor C_{H2} thereby no longer short circuits via the built-in diode of the transistor T_{H5} and the transistor T_{H4} , even when the transistor T_{H4} has been set to ON.

In the bidirectional DC/DC converter according to the third advantageous configuration example shown in FIG. 17, a discharge circuit composed of a resistance R_{H1} and a transistor T_{H6} is provided in parallel to the capacitor C_{H2} . Before the transistor T_{H4} is set to ON in the initial state of step-down operation, the transistor T_{H6} is set to ON and discharging is carried out via the resistance R_{H1} until the voltage at the two ends of the capacitor C_{H2} is substantially 0 V, after which the transistor T_{H6} is set to OFF and the transistor T_{H4} is then set to ON. As a consequence, a large short-circuit electric current no longer flows even when the transistor T_{H4} has been set to ON and the capacitor C_{H2} short circuits via the transistor T_{H4} and the built-in diode of the transistor T_{H5} .

Described next is a bidirectional DC/DC converter according to a fourth advantageous configuration example shown in FIG. 18. The bidirectional DC/DC converter according to a fourth advantageous configuration example shown in FIG. 18 features the use of a normally-on device.

GaN-based transistors, SiC-based transistors, and other compound power devices feature low gate capacity and low on-resistance, and consequently have high expectations as next generation power devices that will replace Si-based power devices. It is difficult to form P-type active layers having low resistance using these compound power devices, and therefore, under current conditions, normally-on N-type devices are generally used. In the case that a normally-on device is used, it is highly likely that the normally-on device will be in an ON state when the driver for driving the normally-on device has failed. Therefore, it is necessary to ensure that short-circuiting or the like does not occur when the driver for driving the normally-on device has failed.

In view of the above, in the bidirectional DC/DC converter according to a fourth advantageous configuration example shown in FIG. 18, normally-on devices are used as the transistors T_{H1} and T_{H3} . It is therefore possible to achieve a reduction in switching loss due to low gate capacity in the transistor T_{H1} as well as a reduction in resistance loss due to low on-resistance; and it is possible to achieve a reduction in switching loss due to low gate capacity in the transistor T_{H3} as well as a reduction in resistance loss due to low on-resistance. Also, safety is ensured because the positive pole and negative pole of the main battery 7 are not short circuited even when either of the transistors T_{H1} and T_{H3} short circuit due to failure. In the bidirectional DC/DC converter according to a fourth advantageous configuration example shown in FIG. 18, the configuration is one in which the transistors T_{H1} and T_{H3} are normally-on devices, and the transistors T_{H2} and T_{H4} are normally-off devices, but the reverse configuration is also possible in which the transistors T_{H1} and T_{H3} are normally-off devices, and the transistors T_{H2} and T_{H4} are normally-on devices. In the case that a compound transistor is used as the

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normally-on device, a built-in diode is not formed between the source and drain in the case of, e.g., a GaN-based transistor. Also, the performance of the built-in diode formed between the source and drain in the case of, e.g., a SiC-based transistor is not good, and it is therefore preferred that a diode be connected in parallel to the normally-on devices (transistors T_{H1} and T_{H3}), as shown in FIG. 18.

The embodiments described above and the details of the modifications described above can be implemented in any combination as long as there is no incompatibility.

What is claimed is:

1. A push-pull circuit comprising:

a first switching element having one end connected to one end of an inductive load and the other end connected to one end of a DC power source;

a second switching element having one end connected to the other end of the inductive load and the other end connected to the one end of the DC power source;

a first rectifier element;

a third switching element for switching a first pathway between conductance and cutoff, the first pathway leading from a connection point between one end of the first switching element and the one end of the inductive load, via the first rectifier element, to a connection point between the other end of the DC power source and a center tap of the inductive load;

a second rectifier element; and

a fourth switching element for switching a second pathway between conductance and cutoff, the second pathway leading from a connection point between one end of the second switching element and the other end of the inductive load, via the second rectifier element, to a connection point between the other end of the DC power source and the center tap of the inductive load;

wherein the first rectifier element and the third switching element are connected in series with each other and disposed on the first pathway,

wherein the second rectifier element and the fourth switching element are connected in series with each other and disposed on the second pathway.

2. The push-pull circuit of claim 1,

each of the first to fourth switching elements being switched ON or OFF so that

the third switching element is in an ON state when the first switching element switches from ON to OFF, and the third switching element is in an OFF state when the second switching element switches from OFF to ON; and

the fourth switching element is in an ON state when the second switching element switches from ON to OFF, and the fourth switching element is in an OFF state when the first switching element switches from OFF to ON.

3. The push-pull circuit of claim 1,

the third switching element and the fourth switching element being normally-off transistors; and

the push-pull circuit further comprising:

a first power source circuit for generating voltage for setting one of the third switching element and the fourth switching element to ON, using the voltage of the connection point between one end of the first switching element and one end of the inductive load; and

a second power source circuit for generating voltage for setting the other of the third switching element and the fourth switching element to ON, using the voltage of the connection point between one end of the second switching element and the other end of the inductive load.

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4. The push-pull circuit of claim 1,
the third switching element and the fourth switching ele-
ment being normally-on transistors.

5. The push-pull circuit of claim 1,
the third switching element and the fourth switching ele- 5
ment being PNP bipolar transistors.

6. The push-pull circuit of claim 1,
the first rectifier element and the second rectifier element
being switching elements for synchronous rectification.

7. The push-pull circuit of claim 6, 10
the first to fourth switching elements, the first rectifier
element, and the second rectifier element being switched
ON or OFF so that
the first rectifier element switches from OFF to ON after
the first switching element has switched from ON to 15
OFF, and the first rectifier element switches from ON to
OFF before the third switching element switches from
ON to OFF; and
the second rectifier element switches from OFF to ON after
the second switching element has switched from ON to 20
OFF, and the second rectifier element switches from ON
to OFF before the fourth switching element switches
from ON to OFF.

8. A DC/DC converter comprising:
a transformer; and 25
a push-pull circuit connected to the transformer,
the push-pull circuit comprising:
a first switching element having one end connected to one
end of an inductive load and the other end connected to
one end of a DC power source; 30
a second switching element having one end connected to
the other end of the inductive load and the other end
connected to the one end of the DC power source;
a first rectifier element;
a third switching element for switching a first pathway 35
between conductance and cutoff, the first pathway lead-
ing from a connection point between one end of the first
switching element and the one end of the inductive load,
via the first rectifier element, to a connection point
between the other end of the DC power source and a 40
center tap of the inductive load;
a second rectifier element; and
a fourth switching element for switching a second pathway
between conductance and cutoff, the second pathway 45
leading from a connection point between one end of the
second switching element and the other end of the induc-
tive load, via the second rectifier element, to a connec-
tion point between the other end of the DC power source
and the center tap of the inductive load;
wherein the first rectifier element and the third switching 50
element are connected in series with each other and
disposed on the first pathway,
wherein the second rectifier element and the fourth switch-
ing element are connected in series with each other and
disposed on the second pathway. 55

9. A solar charging system comprising:
a solar cell;
a first storage device for storing power outputted from the
solar cell;
a second storage device having greater storage capacity 60
than the first storage device; and
a DC/DC converter for DC/DC converting DC voltage
outputted from the first storage device and feeding the
converted voltage to the second storage device;
the DC/DC converter comprising: 65
a transformer; and
a push-pull circuit connected to the transformer; and

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the push-pull circuit comprising:
a first switching element having one end connected to one
end of an inductive load and the other end connected to
one end of a DC power source;
a second switching element having one end connected to
the other end of the inductive load and the other end
connected to the one end of the DC power source;
a first rectifier element;
a third switching element for switching a first pathway
between conductance and cutoff, the first pathway lead-
ing from a connection point between one end of the first
switching element and the one end of the inductive load,
via the first rectifier element, to a connection point
between the other end of the DC power source and a
center tap of the inductive load;
a second rectifier element; and
a fourth switching element for switching a second pathway
between conductance and cutoff, the second pathway
leading from a connection point between one end of the
second switching element and the other end of the induc-
tive load, via the second rectifier element, to a connec-
tion point between the other end of the DC power source
and the center tap of the inductive load;
wherein the first rectifier element and the third switching
element are connected in series with each other and
disposed on the first pathway,
wherein the second rectifier element and the fourth switch-
ing element are connected in series with each other and
disposed on the second pathway.

10. A movable body comprising:
a solar charging system; and
a propelling portion that moves the movable body;
the solar charging system comprising:
a solar cell;
a first storage device for storing power outputted from the
solar cell;
a second storage device having greater storage capacity
than the first storage device; and
a DC/DC converter for DC/DC converting DC voltage
outputted from the first storage device and feeding the
converted voltage to the second storage device; wherein
power output from the second storage device is used as
power for driving the propelling portion;
the DC/DC converter comprising:
a transformer; and
a push-pull circuit connected to the transformer; and
the push-pull circuit comprising:
a first switching element having one end connected to one
end of an inductive load and the other end connected to
one end of a DC power source;
a second switching element having one end connected to
the other end of the inductive load and the other end
connected to the one end of the DC power source;
a first rectifier element;
a third switching element for switching a first pathway
between conductance and cutoff, the first pathway lead-
ing from a connection point between one end of the first
switching element and the one end of the inductive load,
via the first rectifier element, to a connection point
between the other end of the DC power source and a
center tap of the inductive load;
a second rectifier element; and
a fourth switching element for switching a second pathway
between conductance and cutoff, the second pathway
leading from a connection point between one end of the
second switching element and the other end of the induc-
tive load, via the second rectifier element, to a connec-

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tion point between the other end of the DC power source
and the center tap of the inductive load;
wherein the first rectifier element and the third switching
element are connected in series with each other and
disposed on the first pathway,
wherein the second rectifier element and the fourth switch-
ing element are connected in series with each other and
disposed on the second pathway.

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